Investigating Sound Absorption of Oil Palm Trunk Panels Using One-microphone Impedance Tube

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Sound absorption coefficient of oil palm trunk was explored using an impedance tube. Palm samples were taken from the central part of oil palm trunks with cut directions parallel and perpendicular to vascular bundles. Sound absorption was evaluated for palm panels with blind-holes with multiple radii and depths, as well as perforated and grooved panels and a panel with perforated holes at different distances from a solid backing. Measurements of sound absorption within the frequency range of 300-2000 Hz indicated that the sound absorption coefficient of the cross-cut biomass, ~0.15, was slightly greater than that of the parallel-cut panel, ~0.10. Samples with different depths of blind holes showed slight improvements in sound absorption coefficients as compared to the unmodified cross-cut panel. There was a significant improvement for 5-mm hole diameter with 10-mm depth, ~25% improvement as compared to that of 5-mm depth. The combination of the through-hole panel and grooved board allowed ~80% of sound to be absorbed for 1750 to 2000 Hz. Finally, the grooved board was removed and an air cavity backing was introduced by placing the through-hole panel 2-, 4-, and 6-mm away from the tube end. The sound absorption coefficients were then measured to be greater than 80% near the resonance frequencies, as calculated using the distributed Helmholtz resonator model.

Keywords: Oil palm biomass waste; Sound absorption; Impedance tube; Natural acoustic material

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INTRODUCTION

Recently, there has been much interest in using natural materials as sound absorbers due to the potential dangers of the typical materials being generally used, *e.g.*, mineral or glass in fibrous form. Mineral- or glass-fiber can be hazardous to human health and the environment (Su and Cheng 2005; Abbate *et al*. 2006; Asdrubali 2006). Consequently, a number of natural materials and their composites have been investigated for acoustical characteristics (Oldham *et al*. 2011). The cited work indicated that the sound absorption coefficient depends on fiber diameter and porosity. The epoxy/luffa composite treated and untreated with alkalization showed rather similar sound absorption that was improved for the range 500 to 6000 Hz. However, the tensile strength of the treated board was better (Jayamani *et al*. 2014). Rice straw composite boards of three different specific gravities displayed greater acoustic absorption in comparison to that of plywood and fiberboard for frequency above 1 kHz. The composite board with lower specific gravity provided better sound absorption (Yang *et al*. 2003). Fiber loading was an important factor for sound absorption in betel nut fibers reinforced with thermoplastic and thermoset matrix composites. The more loading the greater sound absorption. Overall sound absorption of the composites was however low (Jayamani *et al*. 2014). Four Malaysian woods were studied for their sound absorption coefficients in the frequency range of 350 to 1000 Hz. All woods displayed nearly identical sound absorption characteristics, and their sound absorption coefficients were found to be less than 0.07 (Jayamani *et al.* 2013). Transmission loss and absorption of sound were explored for particleboards having betung bamboo of various particle sizes as a component (Karlinasari *et al*. 2011; Karlinasari *et al.* 2012). The outcome provided that those with low density absorbed sound better than those having high density. However, the sound absorption was inferior for the frequency range of 250 to 800 Hz. The sound absorption coefficient of date palm fiber was determined by placing the fiber chunk between perforated plate and air-backing. It was found that sound absorption was improved for the frequency lesser than 3 kHz and deteriorated for the frequency of 3 to 4 kHz (Elwaleed *et al*. 2013). Furthermore, sound absorber made of sugarcane fibers was also investigated (Putra *et al*. 2013). Tea-leaf-fibre was investigated with and without cotton cloth backing for sound absorption (Ersoy and Küçük 2009). It was clear that those with cotton cloth backing showed better sound absorption. Apparently, various attempts have been made to explore the possibility of using natural materials for sound absorber.

Oil palm is one of the most versatile natural resources. Major cultivation areas are in South-East Asia, *i.e*., Malaysia, Indonesia, and Thailand. Palm oil can be extracted from the tree fruit and is widely used in food and household products. It is also a source of bio-diesel. Due to a dramatic increase in demand for energy, oil palm has been grown extensively. In Thailand, listed as the third in palm oil production in the world, the plantation area is ~5600 km^2 (Anonymous 2010). Typically, oil palm trees last for 25 years (Sulaiman *et al.* 2012). After that, replanting is required. As a result, there is a great amount of felled trees left unused and wasted. Several studies have been done to pursue applications of the leftover palm biomass. Certain parts of the tree were studied for potential uses; for example, the trunk can be employed as compressed wood (Sulaiman *et al.* 2012), frond can be made into composite board (Mat Rasat *et al.* 2011), and its fibers were an important ingredient for sound absorption panels (Elwaleed *et al*. 2013). In addition, different parts of the tree biomass were investigated for mechanical characteristics as they were used to produce particleboards. It was found that those having core-, mid-part, and fronds as ingredients provided acceptable flexibility and strength (Hashim *et al.* 2012). In this work, we investigate the sound absorption coefficient of oil palm biomass cut from the central part of the trunk using a one-microphone impedance tube. The specimens include palm trunk panel cut in parallel and perpendicular to the axial direction of the trunk. Certain modifications, *i.e*., specimens with holes of different diameters and depths as well as perforated and check-board pattern panels, are done to improve the sound absorption coefficients. This work displays the potential of using oil palm trunk as an alternative sound absorber.

EXPERIMENTAL

The experimental setup is shown in Fig. 1. The impedance tube used in this work was constructed in accordance with the American Society for Testing and Materials, ASTM C384-04. It is made of a one-meter polyvinylchloride tube with an 114 mm inner diameter and with a wall thickness of 5 mm. The backing plate of 20 mm thick is made of polished stainless steel. The minimum frequency measurable by this tube (to allow two pressure minima to be observed in the tube) is calculated to be ~292 Hz given the sound speed of 350 m/s (experimentally measured) (ASTM C384-95 1998). To avoid cross mode and the occurrence of transverse waves in the tube, the upper frequency was limited to ~2000 Hz (ASTM C384-95 1998). The experiment was initiated at 300 Hz and then 500 Hz. After that the step-size is 250 Hz up until 2000 Hz. Samples were tightly placed in front of 20-mm thick polished stainless steel disk, located opposite to the loudspeaker. The microphone, B&K Type 4961, was mounted onto one end of a thin metal tube that was axially inserted through the impedance tube. The other end of the tube was attached to a 20-mm translational stage providing horizontal motion to the microphone with 1-mm resolution per step. The loudspeaker was sinusoidally driven by a function generator at 1 $V_{p\text{-}p}$. Acoustic signals from the microphone were recorded by a computerized lock-in amplifier allowing high signal-to-noise ratio measurement. Microphone noise in the tube was measured to be in the microvolt level within the frequency range of the impedance tube, while the measured acoustic signal was over 100 mV. Moreover, the acoustic signal from the microphone was also observed on an oscilloscope. LabView was used to automate the microphone movement and data acquisition. Initially, the microphone was positioned 50 mm away from the sample surface and then pulled toward the speaker by the translational stage at the rate of 3.3 mm/s. The sound responses were measured as microphone voltage in terms of distance to find the maximum (V_{max}) and minimum (V_{min}) voltages as required to calculate the standing wave ratio (SWR=V_{max}/V_{min}) (ASTM C384-95 1998). The absorption coefficient (α) can then be determined from SWR by using:

$$\alpha = 1 - \left|\frac{SWR-1}{SWR+1}\right|^2. \qquad (1)$$

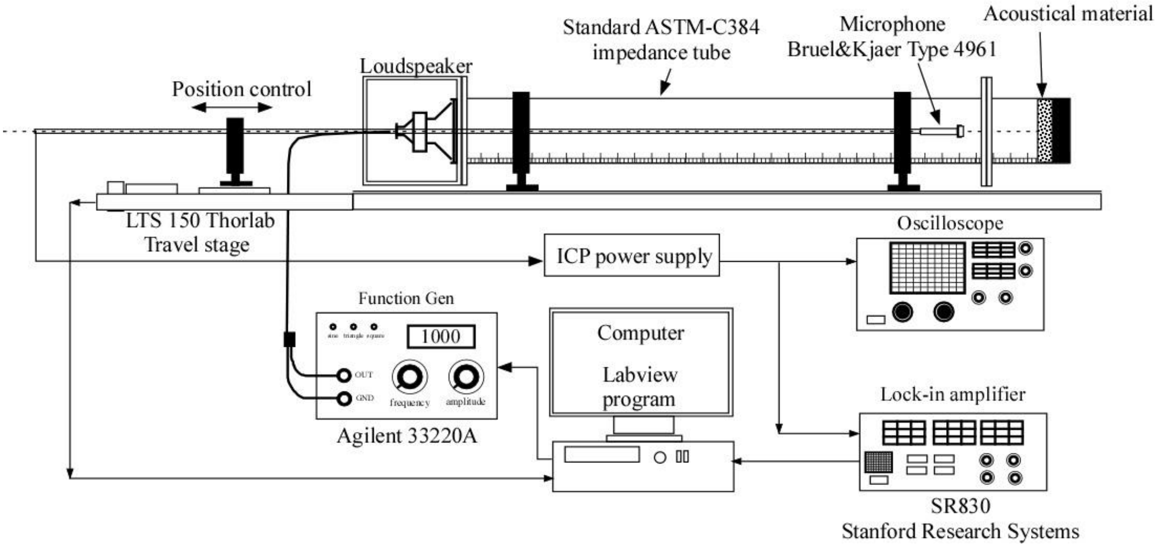

Fig. 1. Experimental setup

To determine possible deviations of the system, *e.g.*, absorption of the tube itself, tests were carried out in which the tube was operated with only a solid backing, which should result in null absorption. However, the result yielded certain values of absorption coefficients, less than 0.05 on average for the dedicated frequency range. This amount was then treated as background absorption and subtracted from that of the experiment.

SAMPLE PREPARATION

The samples were extracted from the central area of the palm trunk. The dry biomass was subjected to a cutting process in which two cutting directions, parallel and perpendicular to the vascular bundles, were obtained. The density of the biomass was 340 kg m^{-3}. Each fiber has the average dimensions of about 30-μm in diameter and

1.24-mm in length and yields the density of 0.41 g/cm^3 (Erwinsyah 2008). The samples were later milled to yield cylindrical geometry of 12 and 14 mm thickness. The panel diameter was 114 mm, made to be fit the impedance tube. A computer numerical control (CNC) router was used to make through and blind holes as well as the stripe patterns on the biomass panel. In this work, the samples can be classified as follows:

1. Oil palm biomass panels of the two cut directions, shown in Figs. 2(a) and 2(b). Their thickness is 14 mm.
2. The cross-cut panels with blind holes of 3-, 5-, and 8-mm diameters and 5-, 7.5-, and 10-mm depths, shown in Fig. 2(c). Their thickness is 12 mm.
3. The 12-mm thick parallel-cut panels with 3-mm wide checkerboard-patterned grooves with 3-mm depth and 3-mm diameter through holes, displayed in Figs. 2(d) and (e), respectively.
4. The through-hole panel is also used to explore the effect of air backing on sound absorption.

The physical dimensions of the modified panels are shown in Figs. 2(f), (g), and (h). In Fig. 2(f). The cross-cut disk is shown. It was drilled to yield the diameters, *d*, of 3, 5, and 8 mm. Each hole had 10 mm separation. The hole depths, *h*, were specified to be 5, 7.5, and 10 mm. Figures. 2(g) and (h) present the physical dimensions of the patterned and perforated panels, respectively. The patterned panel in Fig. 2(g) had 3-mm groove width and depth. Each groove was located 10 mm apart, while the perforated holes in Fig. 2(h) had 3-mm diameter.

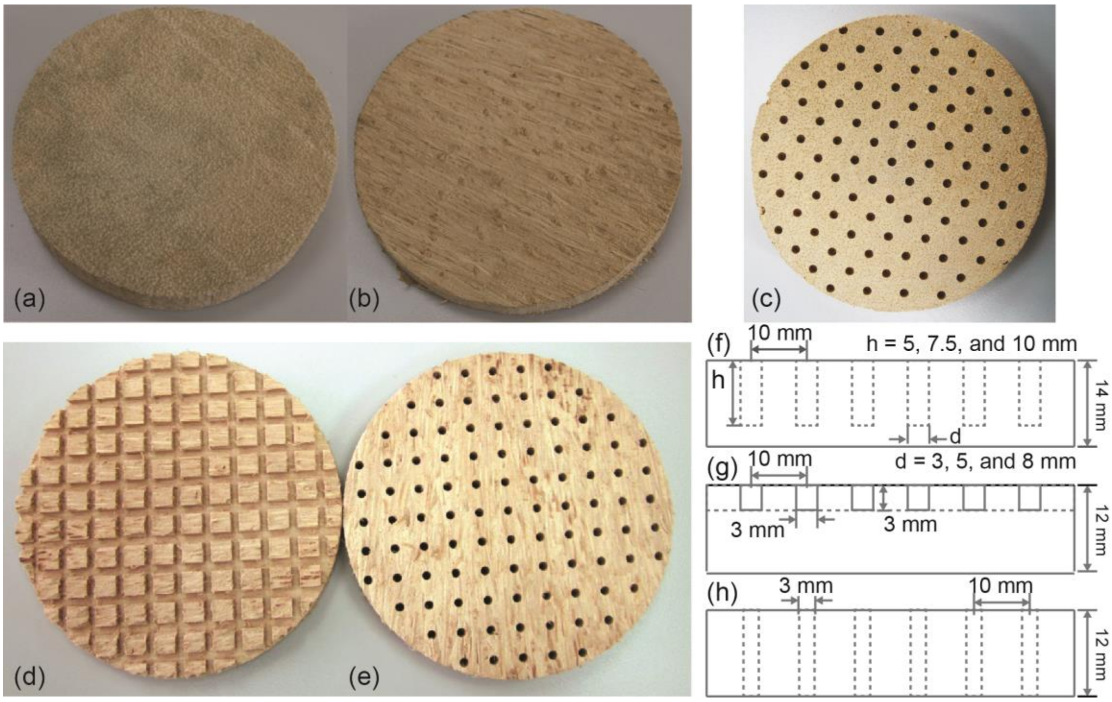

Fig. 2. Palm biomass samples. (a) and (b) are respectively cross-cut and parallel-cut samples. (c) and (f) show the panel with orderly arranged blind holes and their physical dimensions. (d) and (e) present the patterned and perforated oil palm panels where (g) and (h) indicate the dimensions of the grooves and holes.

RESULTS AND DISCUSSION

Scanning electron micrographs (50×) of the surface of oil palm trunk for different cut directions can be seen in Figs. 3(a) and (b). The parallel-cut sample displays channels with random diameters. The experimental result for sound absorption coefficients is shown in Fig. 4.

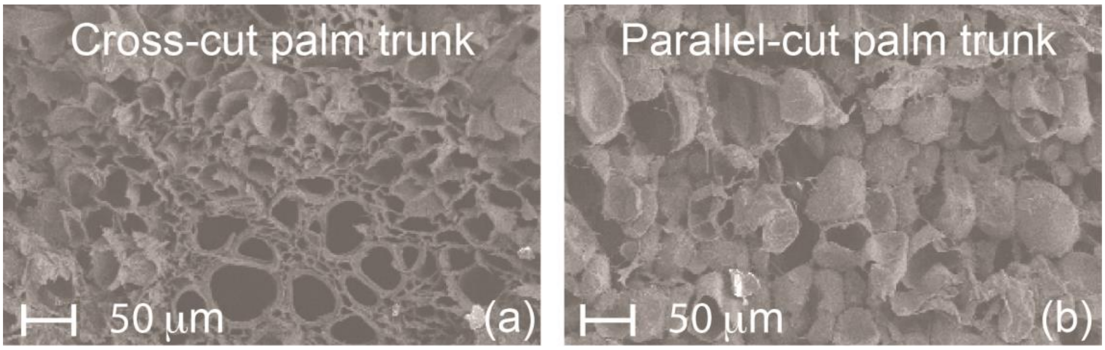

Fig. 3. Scanning electron micrographs of (a) cross-cut and (b) parallel-cut panels. Taken at 50X magnification.

It is apparent that the cross-cut panel provided slightly greater sound absorption than that of parallel-cut panel. The parallel-cut panel showed a nearly constant sound absorption coefficient, ~0.1, regardless of frequency, whereas the cross-cut panel provided slight improvement, ~0.15. Such distinction in sound absorption coefficients may possibly be due to the porosity and flow resistivity of the panels as a result of cutting directions. Using the water displacement method for the porosity estimation, it was found that the parallel-cut panel yielded the porosity of ~0.62. On the other hand, the cross-cut panel showed somewhat greater porosity of ~0.76. These values are typical for wooden material (Cox and D' Antonio 2009). Using the mean diameter of 30 μm for the palm trunk fiber and the air viscosity of 1.84×10^{-5} Pa.s, one can estimate the flow resistivity for the cross-cut and for parallel-cut to be ~1.99×10^5 and 3.28×10^5 Pa.s m^{-2}, respectively (Mechel 2002). It is apparent that the cross-cut sample had a lower value of flow resistivity than that of parallel-cut sample.

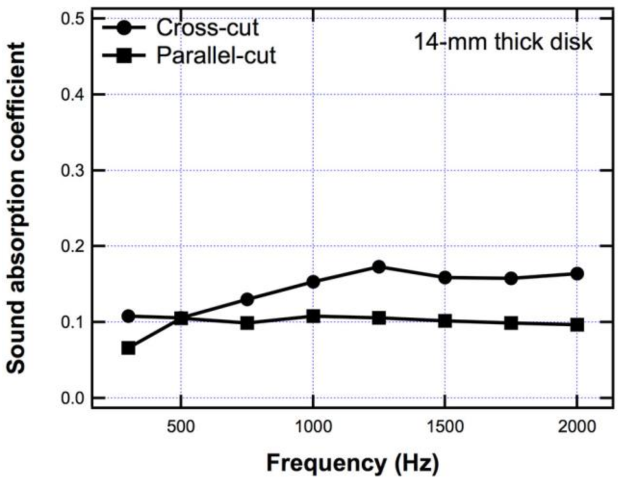

Fig. 4. Sound absorption coefficients of oil palm biomass of the two cuts in terms of frequency.

For the organized blind holes of different diameters and depths, including those of the flat panel, the sound absorption coefficients are shown in Figs. 5(a), (b), and (c). It is apparent that the organized holes helped to improve the sound absorption property. However, the panel with 3-mm diameter holes provides minor enhancement as seen in Fig. 5(a). The depth dependence of sound absorption was apparent but rather small. The absorption coefficient was maximum, ~ 0.24, at 2000 Hz for 7.5-mm depth while that of flat specimen was about 0.17 at 2000 Hz. The acoustic wave tended to be reflected strongly by this specimen due to acoustical stiffness of the closed-end holes being inversely proportional to the volume of the hole. Therefore, the sound tends to be reflected for the panel with 3 mm diameter blind holes. On the other hand, for the panel with 5-mm hole diameter, Fig. 5(b), the sound absorption clearly varied with the cavity depth for the frequency above 500 Hz. The deeper the cavity, more volume, the better the sound absorption. The absorption for 5-mm depth began to increase at 750 Hz whereas the others displayed a gradual rise as frequency was increased. The improvement in absorption property for 5-mm hole depth was nearly twice, ranging from 0.2 to 0.28, that of the flat disk for frequencies above 1250 Hz. On the contrary, the enhancement in absorption in low frequency region (<1000 Hz) was less than 50% in comparison to that of the no-hole sample. The 10-mm hole depth specimen was the best sound absorbing panel. Its maximum, about 0.4, appeared at 2000 Hz. It also possessed greater sound absorption than that of other specimens for frequency above 500 Hz.

Increasing the diameter to 8 mm, the sound absorption is improved as compared to the flat disk as seen in Fig. 5(c). Nevertheless, the absorption was generally inferior to that of the 5-mm hole diameter panel for every depth. This is possibly due to the smaller frictional loss as a result of wider holes, since air mass can flow easily causing less energy dissipation. As a result, the absorption performance is less enhanced.

To further explore the sound absorption property, the palm biomass with checkerboard-like grooved and perforated disks of 12 mm thickness were separately and altogether investigated. The results are, respectively, shown in Figs. 6(a) and (b). Each individual displayed poor absorption property; however, when they were stacked together—perforated front and grooved back—the absorption was dramatically improved, as can be seen in Fig. 6(b). The absorption rose up as high as 0.80 at 1750 Hz. In addition, the effect of back-plate rotation to the absorption was checked. Such experiments yielded neither improvement nor deterioration. It is speculated that the groove pattern, which has channels filled with air, behaves like the backing of Helmholtz resonators with the air volume of 5036 mm^3, corresponding to 0.5-mm spacing to the solid backing. Using a distributed Helmholtz model (Vigran 2008), it is possible to estimate the resonant frequency to be 5748 Hz. Besides, as confirmed by various researchers (Zulkifli *et al.* 2008; Elwaleed *et al*. 2013), the addition of a perforated plate slightly improves the absorption in the low frequency region (<2000 Hz); though in the present case the enhancement was substantial, nearly eight-fold at 1750 Hz.

In addition, experiments concerning the sound absorption of a perforated panel with 3-mm hole diameter and air space backing were investigated by placing the panel at 3 distances—2, 4, and 6 mm—away from the solid backing. Such holes provide the flow resistivity of 65 Pa.s m^{-2} (Vigran 2008). The results are shown in Fig. 7. One can observe apparent enhancement in sound absorption for all spacing with the maximum values in consistent with resonant frequencies (f_{res}) of distributed Helmholtz resonators (Vigran 2008), calculating from,

$$f_{res} = \frac{c_0}{2\pi}\sqrt{\frac{\varepsilon}{l(d+\Delta d)}} \quad (2)$$

where c_0 and ε are the sound speed in air, 350 m/s, and the perforation or the filling fraction of the panel, ~0.07, respectively. The quantity l, 12 mm, is the distance (much less than the sound wavelength) to the solid backing, whereas d and Δd are respectively the thickness of the panel and end correction factor, $0.85a$, where a is the radius of the resonator. The resulting resonant frequencies were 2874.4, 2032.5 and 1659.5 Hz, corresponding to 2, 4 and 6 mm spacing, respectively, which are all higher than actual experimental frequencies—1500 and 1760 Hz for 4- and 6-mm spacing. For 2-mm air spacing, the frequency exceeded the measurement limitation. The deviations for each spacing were 9 and 13%, respectively. Nevertheless, the improvement in sound absorption was dramatic in all spacing near resonant frequencies, more than 0.8. It is quite clear that the palm trunk can be another alternative for sound absorbing material but further studies are still necessary to investigate its mechanical properties and durability against everyday uses.

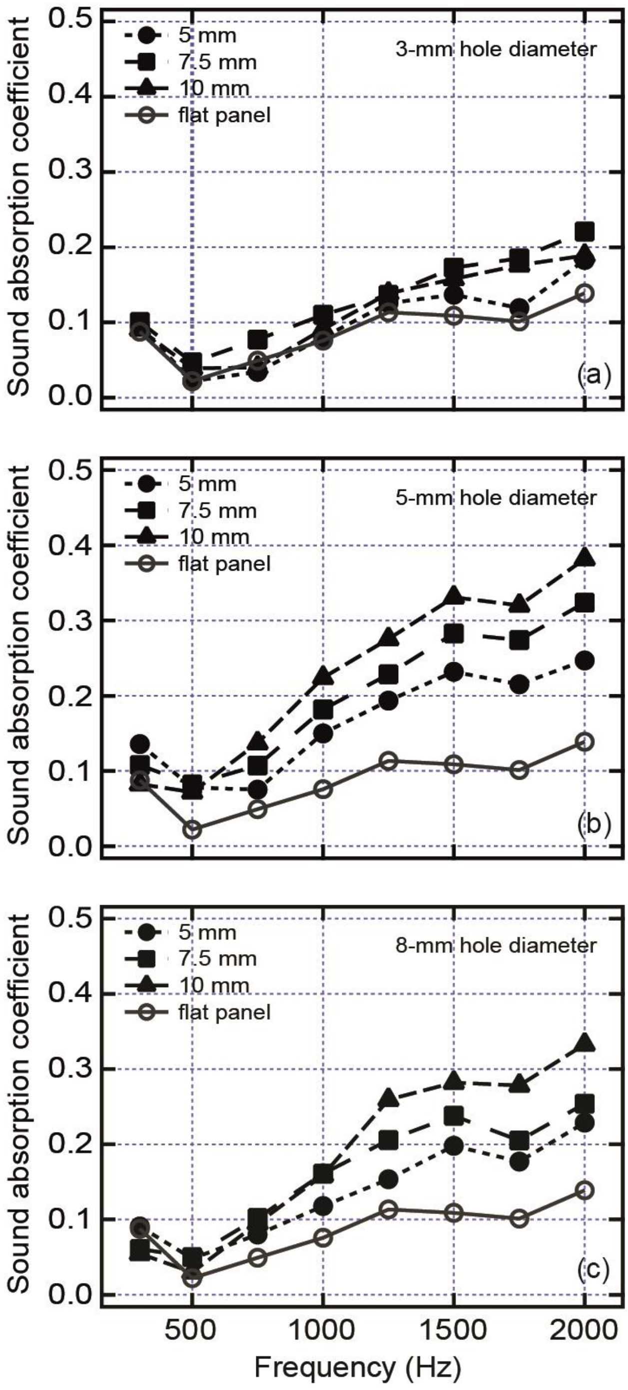

Fig. 5. Sound absorption coefficients of 12 mm thick cross-cut palm biomass with (a) 3 mm hole diameter, (b) 5 mm hole diameter and (c) 8 mm hole diameter. Each graph shows the absorption coefficients for panels with holes of different depths—5-, 7.5-, and 10-mm as well as that for the cross-cut flat panel.

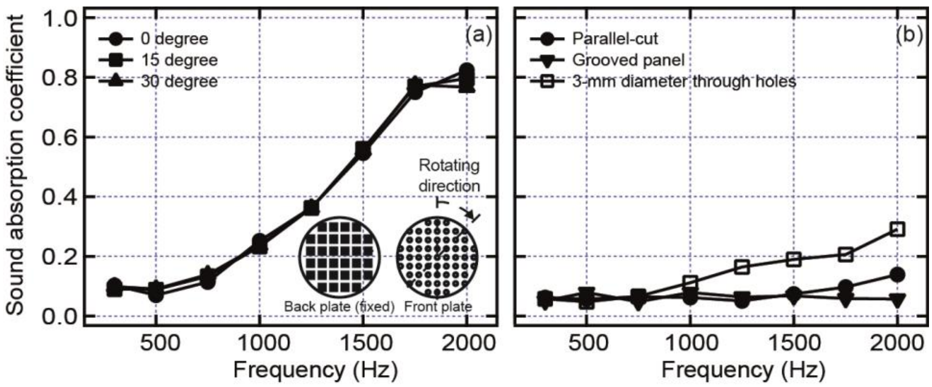

Fig. 6. (a) Sound absorption coefficients of parallel-cut, grooved, and perforated specimens and (b) sound absorption of stacked panels of which the front and back plates are respectively perforated and grooved plate as shown on the lower right corner

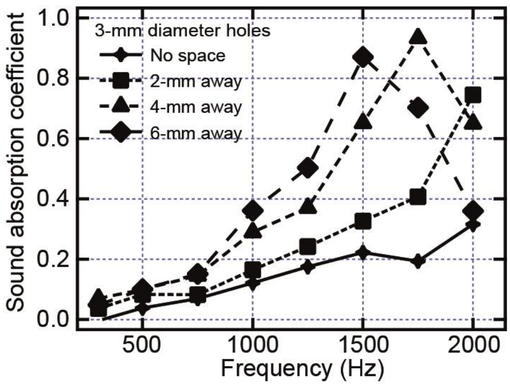

Fig. 7. Sound absorption coefficients of the 3 mm hole diameter perforated panel at 0, 2, 4, and 6 mm away from the tube end allowing air cavity backing

CONCLUSIONS

1. Unmodified oil palm biomass waste shows small sound absorption performance. Cut directions yields different sound absorption, for which the cross-cut panel possesses better sound absorption than the parallel-cut panel.
2. Blind holes of various depths and diameters improve the absorption property. The panel with 5-mm diameter holes is the most enhanced specimen. The frictional loss is probably the key effect for such enhancement. However, care must be taken in choosing hole diameter since too wide or too narrow can significantly affect the absorption characteristics of the biomass panel.
3. Perforated panel stacked with a checkerboard-patterned disk provides substantial increase in sound absorption, even though each panel individually shows marginal absorption. The volume of checkerboard grooves in this case possibly acts like an air cavity of which has the volume of 5036 mm^3 corresponding to air space of 0.5 mm width. Its resonant frequency, using distributed Helmholtz model, is 5748 Hz. Such frequency is out of the measurement range.
4. The panel with 3-mm diameter through hole is tested with air-spacing of 2-, 4-, and 6-mm. The sound absorption coefficients are significantly improved, particularly near the resonant frequency of distributed Helmholtz resonator. It is typical to find the actual frequency is lower than the calculated one.

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